Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego monitors oceanographic conditions in the region surrounding the South Bay Ocean Outfall (SBOO) to assist in evaluating possible impacts of wastewater discharge on the marine environment. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen and pH, in conjunction with biological indicators such as chlorophyll concentrations, are important indicators of biological and physical oceanographic processes (Skirrow 1975) that can impact marine life within a region (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and the rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., horizontal and vertical mixing of the water column, current patterns), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping.

In relatively nearshore waters such as the SBOO monitoring region, oceanographic conditions are strongly influenced by seasonal changes (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather can generally be classified into a wet, winter season (typically December through February) and a dry, summer season (typically July through September) (NOAA/NWS 2010), and differences between these seasons affect oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves which often contribute to the formation of a well-mixed, relatively homogenous or non-stratified water column (Jackson 1986). The chance that wastewater plumes from sources such as the SBOO may surface is highest during such times when the water column is well mixed and there is little, if any, stratification. These conditions often extend into spring as the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the increasing elevation of the sun and longer days begin to warm surface waters resulting in increased surface evaporation (Jackson 1986). Mixing conditions also diminish with decreasing storm activity, and seasonal thermoclines and pycnoclines become re-established. Once the water column becomes stratified again by late spring, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes like the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment, contaminant) plumes. In the South Bay outfall region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in U.S. waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1075 km^2 and 4483 km^2 of watershed, respectively, and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009). Overall, these different sources can affect water quality conditions both individually and synergistically.

This chapter describes the oceanographic conditions that occurred in the South Bay outfall region during 2010. The main objectives are to: (1) describe deviations from expected oceanographic patterns,

(2) assess possible influence of the SBOO wastewater discharge relative to other input sources, (3) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials, and (4) demonstrate the influence of natural events such as storms or El Niño/La Niña oscillations. The results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejkovsky 2011). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

Materials and Methods

Field Sampling

Oceanographic measurements were collected at fixed sampling sites located in a grid pattern encompassing an area of ~300 km^2 surrounding the SBOO (Figure 2.1). These forty offshore stations (designated I1–I40) are located ~3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly, usually over a 3-day period; the only exception was during April 2010 when offshore water quality sampling was not conducted due to a Bight'08 resource exchange. Sites were grouped together during each sampling period as follows: "North Water Quality" stations I28–I38 ($n = 11$); "Mid Water Quality" stations I12, I14–I19, I22–I27, I39, I40 ($n = 15$); "South Water Quality" stations I1–I11, I13, I20, I21 ($n = 14$). See Appendix A.1 for the actual dates samples were collected during 2010.

Data for the various oceanographic parameters were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), and dissolved oxygen (DO). Profiles of each parameter were then constructed for each station by averaging the data values recorded over 1-m depth intervals. This data reduction ensured that physical measurements used in subsequent analyses could correspond to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather and water conditions were recorded just prior to each CTD cast.

Remote Sensing – Aerial and Satellite Imagery

Coastal monitoring of the SBOO region during 2010 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite and aerial imaging data collected during the year are made available for review and download from OI's website (Ocean Imaging 2011), while a separate annual report to summarize these data

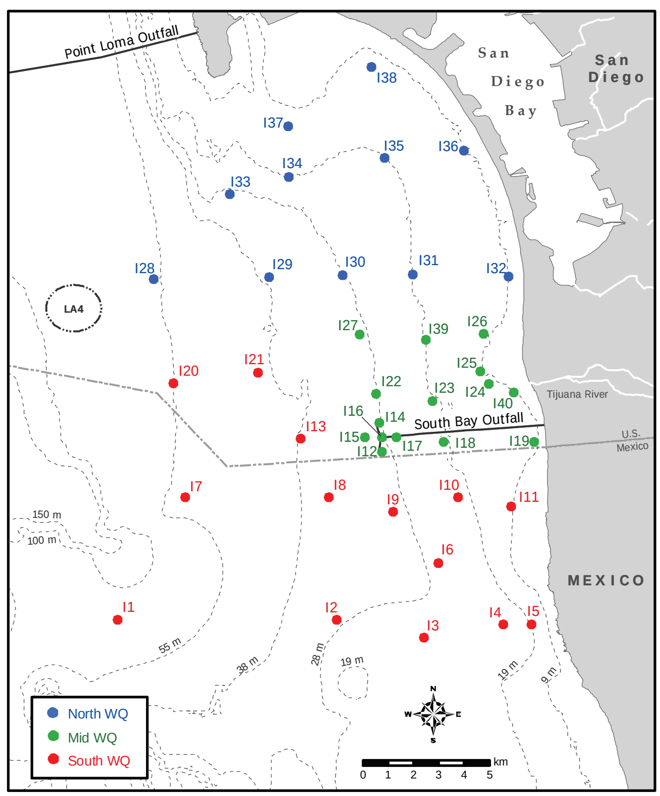

Figure 2.1
Water quality (WQ) monitoring stations where CTD casts are taken, South Bay Ocean Outfall Monitoring Program.

is also produced (Svejkovsky 2011). This chapter includes examples of Thematic Mapper TM5 thermal satellite imagery. Examples of multispectral color imagery from OI's DMSC-MKII aerial sensor and thermal infrared (IR) imagery from a Jenoptik thermal imager integrated into the system are also included. Additionally, color images from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite are included in the Water Quality chapter (see Chapter 3). These technologies differ in terms of their resolution, frequency of collection, depth of penetration, and detection capabilities as described in the "Technology Overview" section of Svejkovsky (2011).

Data Treatment

The various water column parameters measured in 2010 were summarized as monthly means of surface (top 2 m) and bottom (bottom 2 m) waters over all stations located along each of the 9, 19, 28, 38 and 55-m depth contours to provide an overview of trends throughout the entire year. For spatial analysis, 3-dimensional graphical views were created for each month using Interactive Geographical Ocean Data System software (IGODS), which uses a linear interpolation between stations and with depth at each site. In most cases, inclusion of these analyses was limited herein to four monthly surveys representative of the winter (February), spring (May), summer (August), and fall (November) seasons. These surveys were selected because they correspond to the quarterly water quality surveys typically conducted as part of the coordinated Point Loma Ocean Outfall (PLOO) and Central Bight Regional monitoring efforts. Additional analysis included vertical profiles using the 1-m binned data for each parameter from the same surveys listed above, but limited to a subset of seven stations along the 28-m depth contour (i.e., stations I3, I9, I12, I14, I16, I22, I27). These profiles were created to provide a more detailed view of data depicted in the IGODS graphics. Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events in the region. Anomalies were calculated by subtracting the monthly means for each year between 1995–2010 from the mean of all 16 years combined. These mean values were calculated using data from all of the 28-m depth contour stations, with all water column depths combined.

Results

Oceanographic Conditions in 2010

Water temperature and density

Seawater density is a product of temperature, salinity and pressure. In the shallower coastal waters of southern California, density is influenced primarily by temperature differences since salinity is relatively uniform (Bowden 1975, Jackson 1986, Pickard and Emery 1990). This relationship was evident in the South Bay outfall region during 2010 as indicated by the strong correlation between temperature and density (Pearson correlation coefficient $r(11,119) = 0.99$, $p < 0.001$; Figure 2.2). However, some deviations occurred as a result of fresh water runoff into the survey area during February, March, and December; each were months with relatively high levels of rainfall (see Table 3.1 for rainfall levels). Because of this strong relationship, changes in density typically mirror those in water temperatures, and results discussed below for temperature can be assumed to also apply to density.

Mean surface temperatures across the entire SBOO region ranged from 12.9°C in December to 19.1°C in October, while bottom temperatures averaged from 10.2°C in June to 16.4°C in October in 2010 (Table 2.1). Overall, these surface and bottom water temperatures were lower than during 2009. For example, surface temperatures peaked in September 2009 at about 21ºC (City of San Diego 2010). As expected, the lowest temperatures of the year occurred at bottom depths during the spring and summer (Table 2.1, Figure 2.3, Figure 2.4). These colder bottom waters, which likely reflect coastal upwelling, entered the SBOO region as early as February at northern offshore stations (Figure 2.4A). Temperatures also varied as expected by season, with the water column ranging

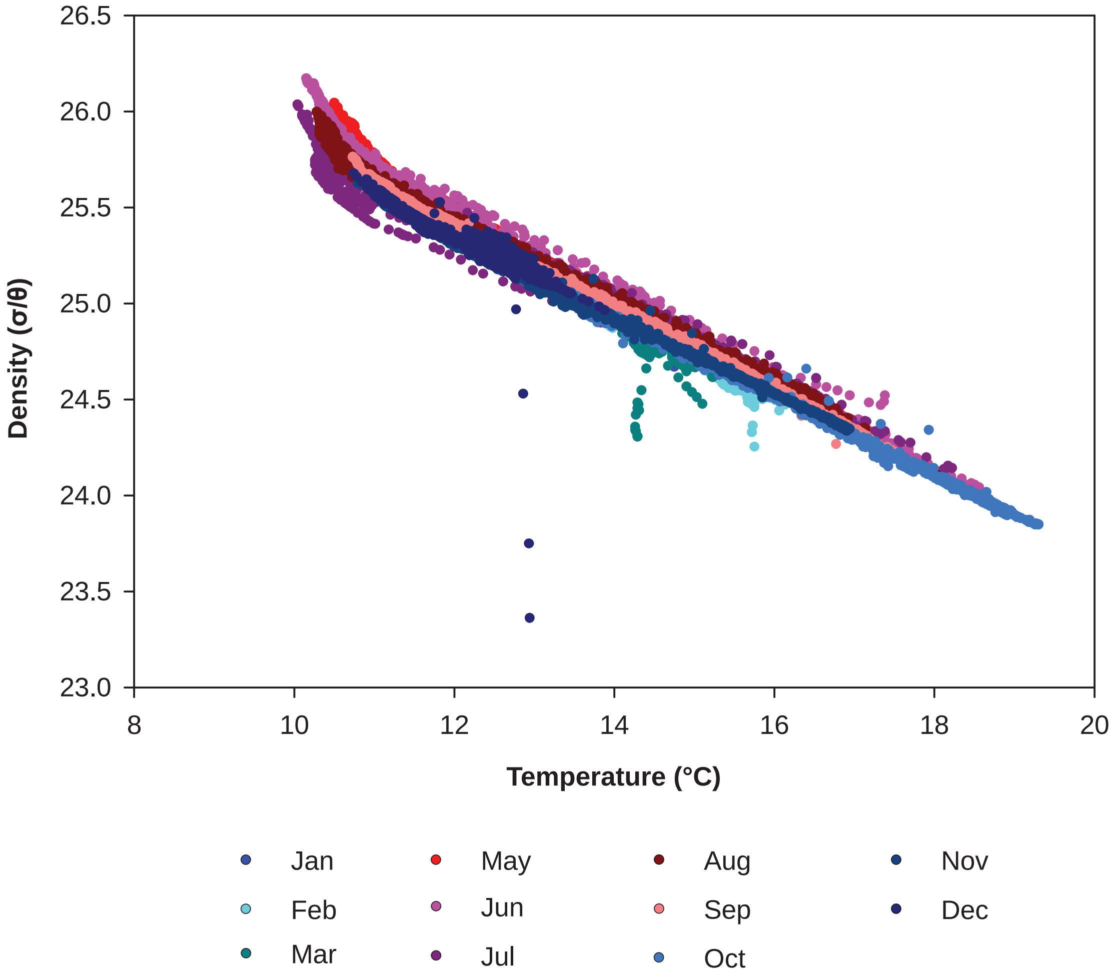

Figure 2.2
Scatterplot of temperature and density for SBOO stations sampled in 2010.

from mixed in the winter, to highly stratified in late summer/early fall, to less stratified in late fall. However, the water column was not as well-mixed during January and February 2010 as it has been in previous years, with average temperatures differing between surface and bottom depths by as much as 3ºC. Since temperature is the main contributor to water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations and discrete bacteriological samples indicated that the plume surfaced during January, February, March and December when the water column was more mixed, but was never detected in surface waters between April and November, when the water column was stratified enough to keep the plume submerged (e.g., Figure 2.5; see also Svejkovsky 2011).

Salinity

Average salinities for surface waters in the SBOO region ranged from a low of 33.18 psu in December to a high of 33.57 psu in June and July, and from 33.36 psu in November to 34.00 psu in June at bottom depths (Table 2.1). Relatively low salinity values (e.g., < 33.50 psu) were observed at the surface across parts of the region during the rainy months of January, February, March and December, often with the lowest values at stations located near the mouth of the Tijuana River or the entrance to San Diego Bay (e.g., Figure 2.6A). In contrast, high salinity values (e.g., > 33.65 psu) extended across most of the region at bottom depths in the spring and summer and correspond to the lower temperatures found at bottom depths as described

Table 2.1

Summary of temperature, salinity, dissolved oxygen, pH, transmissivity, and chlorophyll *a* for surface and bottom waters in the SBOO region during 2010. Values are expressed as means for each month pooled over all stations along each depth contour.

Depth	Contour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (ºC)													
9-m	Surface	14.71	15.61	13.21	ns	15.00	17.65	14.84	15.39	16.26	18.19	15.61	13.05
	Bottom	14.60	14.85	12.72	ns	12.29	15.85	11.49	11.90	15.30	16.41	14.78	12.69
19-m	Surface	14.86	15.60	13.67	ns	15.96	17.31	14.99	15.48	16.48	18.38	15.81	12.88
	Bottom	14.65	14.16	12.31	ns	11.40	11.48	10.65	10.75	12.66	14.59	13.09	12.19
28-m	Surface	14.91	15.57	13.76	ns	15.79	16.81	15.84	16.36	16.80	18.72	16.19	12.97
	Bottom	14.74	13.81	11.34	ns	10.94	10.73	10.41	10.51	11.91	13.28	12.36	11.93
38-m	Surface	15.24	15.72	14.48	ns	15.96	16.38	15.52	16.42	17.10	18.89	16.58	13.09
	Bottom	14.72	12.86	11.05	ns	10.77	10.38	10.29	10.46	11.45	12.39	11.94	11.38
55-m	Surface	15.26	15.54	14.78	ns	15.24	16.86	17.80	16.37	17.01	19.08	16.64	13.38
	Bottom	13.94	12.58	10.91	ns	10.61	10.22	10.27	10.32	10.91	11.20	11.08	11.04
Salinity (psu)													
9-m	Surface	33.40	33.32	33.26	ns	33.50	33.52	33.54	33.50	33.46	33.47	33.40	33.41
	Bottom	33.40	33.38	33.44	ns	33.54	33.57	33.50	33.54	33.46	33.42	33.39	33.42
19-m	Surface	33.39	33.36	33.40	ns	33.51	33.50	33.55	33.51	33.44	33.47	33.41	33.41
	Bottom	33.40	33.41	33.51	ns	33.62	33.66	33.54	33.61	33.47	33.38	33.36	33.44
28-m	Surface	33.37	33.36	33.38	ns	33.52	33.51	33.54	33.52	33.47	33.51	33.42	33.18
	Bottom	33.39	33.42	33.63	ns	33.73	33.70	33.58	33.66	33.49	33.39	33.36	33.41
38-m	Surface	33.41	33.34	33.36	ns	33.50	33.53	33.53	33.54	33.46	33.52	33.45	33.37
	Bottom	33.39	33.46	33.69	ns	33.79	33.81	33.65	33.77	33.49	33.40	33.39	33.44
55-m	Surface	33.43	33.39	33.35	ns	33.49	33.57	33.57	33.44	33.46	33.54	33.44	33.39
	Bottom	33.40	33.49	33.71	ns	33.90	34.00	33.65	33.80	33.57	33.45	33.43	33.48
Dissolved Oxygen (mg/L)													
9-m	Surface	7.98	7.97	7.35	ns	8.21	9.95	7.55	9.91	9.22	7.85	8.49	8.51
	Bottom	7.76	7.33	6.34	ns	5.39	7.94	5.56	6.78	8.37	7.58	7.37	7.66
19-m	Surface	7.88	7.94	7.75	ns	8.87	9.17	7.69	10.34	9.34	8.04	8.74	8.50
	Bottom	7.53	6.77	5.82	ns	3.61	5.13	5.18	4.56	6.19	7.22	6.16	7.21
28-m	Surface	7.54	8.07	8.04	ns	8.68	8.50	7.97	10.58	8.77	7.77	8.41	8.61
	Bottom	7.31	6.45	4.78	ns	2.94	3.99	5.05	4.31	4.91	6.61	6.01	6.45
38-m	Surface	7.56	8.13	8.73	ns	8.82	8.66	7.94	10.23	8.83	7.63	8.48	9.36
	Bottom	7.18	5.72	4.43	ns	2.84	3.42	4.56	3.46	4.92	6.03	5.53	5.70
55-m	Surface	7.35	8.13	9.00	ns	8.74	8.28	8.28	8.75	8.55	7.54	8.27	8.72
	Bottom	6.22	5.49	4.35	ns	2.73	2.45	4.63	3.70	4.28	5.62	5.98	5.53

ns = not sampled (see text)

Table 2.1 *continued*

Depth	Contour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
pH													
9-m	Surface	8.19	8.15	8.05	ns	8.22	8.34	8.02	8.24	8.25	8.26	8.15	8.17
	Bottom	8.18	8.11	8.00	ns	7.94	8.20	7.87	8.05	8.18	8.20	8.08	8.09
19-m	Surface	8.19	8.17	8.10	ns	8.31	8.27	8.03	8.27	8.27	8.26	8.20	8.16
	Bottom	8.17	8.07	7.98	ns	7.79	7.91	7.79	7.85	8.00	8.15	7.96	8.02
28-m	Surface	8.17	8.17	8.14	ns	8.28	8.20	8.08	8.29	8.25	8.26	8.19	8.18
	Bottom	8.15	8.05	7.90	ns	7.74	7.80	7.77	7.81	7.89	8.08	7.92	7.95
38-m	Surface	8.17	8.20	8.23	ns	8.28	8.21	8.10	8.29	8.26	8.24	8.20	8.20
	Bottom	8.14	7.99	7.87	ns	7.73	7.75	7.75	7.76	7.91	8.01	7.88	7.89
55-m	Surface	8.10	8.17	8.22	ns	8.23	8.18	8.18	8.20	8.23	8.23	8.18	8.16
	Bottom	8.03	7.96	7.85	ns	7.70	7.67	7.93	7.76	7.83	7.95	7.89	7.86
Transmissivity (%)													
9-m	Surface	71.40	58.60	55.75	ns	67.55	63.75	71.25	67.25	69.80	80.25	77.20	74.05
	Bottom	70.76	46.22	58.35	ns	66.52	74.23	73.37	63.18	76.63	71.64	74.33	72.09
19-m	Surface	79.50	73.72	71.33	ns	74.22	73.94	77.06	69.89	75.28	83.22	83.06	78.39
	Bottom	77.00	63.65	75.00	ns	67.83	75.65	85.21	79.75	80.35	76.46	77.39	74.29
28-m	Surface	82.15	77.88	78.46	ns	82.04	81.85	78.73	71.81	80.77	89.04	86.42	79.23
	Bottom	78.76	74.43	82.07	ns	75.00	84.78	89.48	85.75	83.60	81.29	85.45	83.08
38-m	Surface	87.00	83.38	79.63	ns	85.38	75.13	81.63	71.63	82.75	90.00	87.75	77.75
	Bottom	82.58	77.38	83.25	ns	74.70	89.00	89.83	82.58	87.62	86.27	87.58	81.40
55-m	Surface	88.50	85.63	77.13	ns	85.63	83.38	82.88	81.88	85.50	90.00	88.50	81.38
	Bottom	86.93	85.43	85.86	ns	86.57	88.91	89.57	88.36	89.00	90.79	90.64	89.14
Chlorophyll *a* (µg/L)													
9-m	Surface	8.94	4.47	7.49	ns	12.87	29.72	5.58	23.07	25.00	8.03	8.40	7.26
	Bottom	10.70	7.21	8.22	ns	23.34	10.90	7.38	40.63	11.73	9.32	8.83	7.61
19-m	Surface	3.32	3.03	6.16	ns	6.25	13.15	5.53	16.33	12.69	8.40	3.93	8.05
	Bottom	4.71	3.93	5.13	ns	30.24	18.93	3.40	15.29	6.91	7.20	5.61	11.24
28-m	Surface	2.60	2.45	3.77	ns	2.61	3.79	4.55	9.86	6.99	3.19	2.05	6.57
	Bottom	4.40	3.38	1.82	ns	24.70	9.44	1.56	6.38	5.61	5.43	6.28	7.91
38-m	Surface	2.19	1.41	3.20	ns	1.42	6.98	3.00	8.43	2.73	2.02	1.45	11.93
	Bottom	3.70	1.46	1.36	ns	31.13	1.81	0.99	9.63	3.39	3.32	2.58	5.40
55-m	Surface	2.15	1.82	7.65	ns	2.35	5.43	2.31	6.96	3.17	2.14	1.58	12.08
	Bottom	2.29	1.17	0.69	ns	4.62	0.77	0.83	0.58	1.75	1.63	1.59	2.41

ns = not sampled (see text)

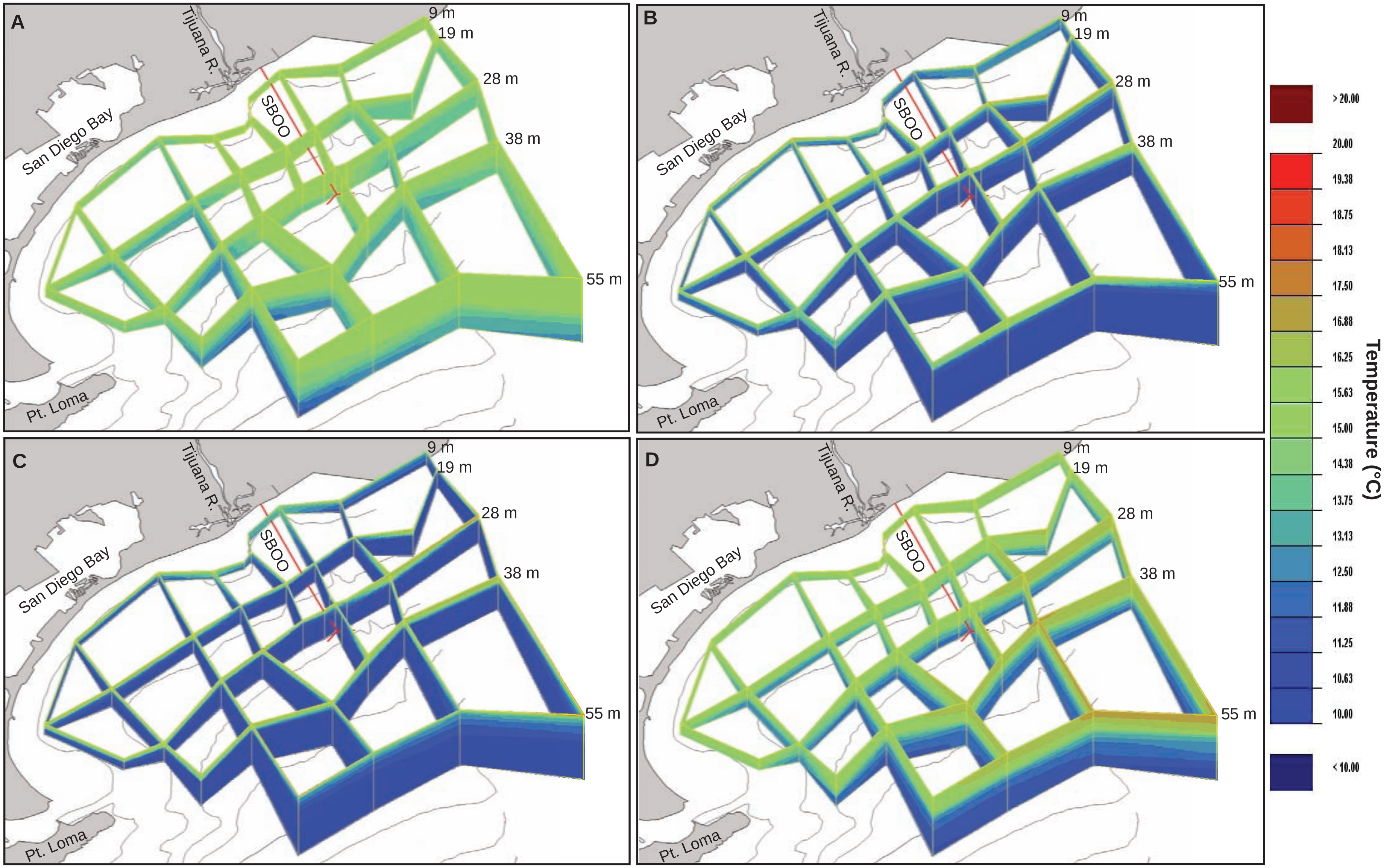

Figure 2.3

Ocean temperatures recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

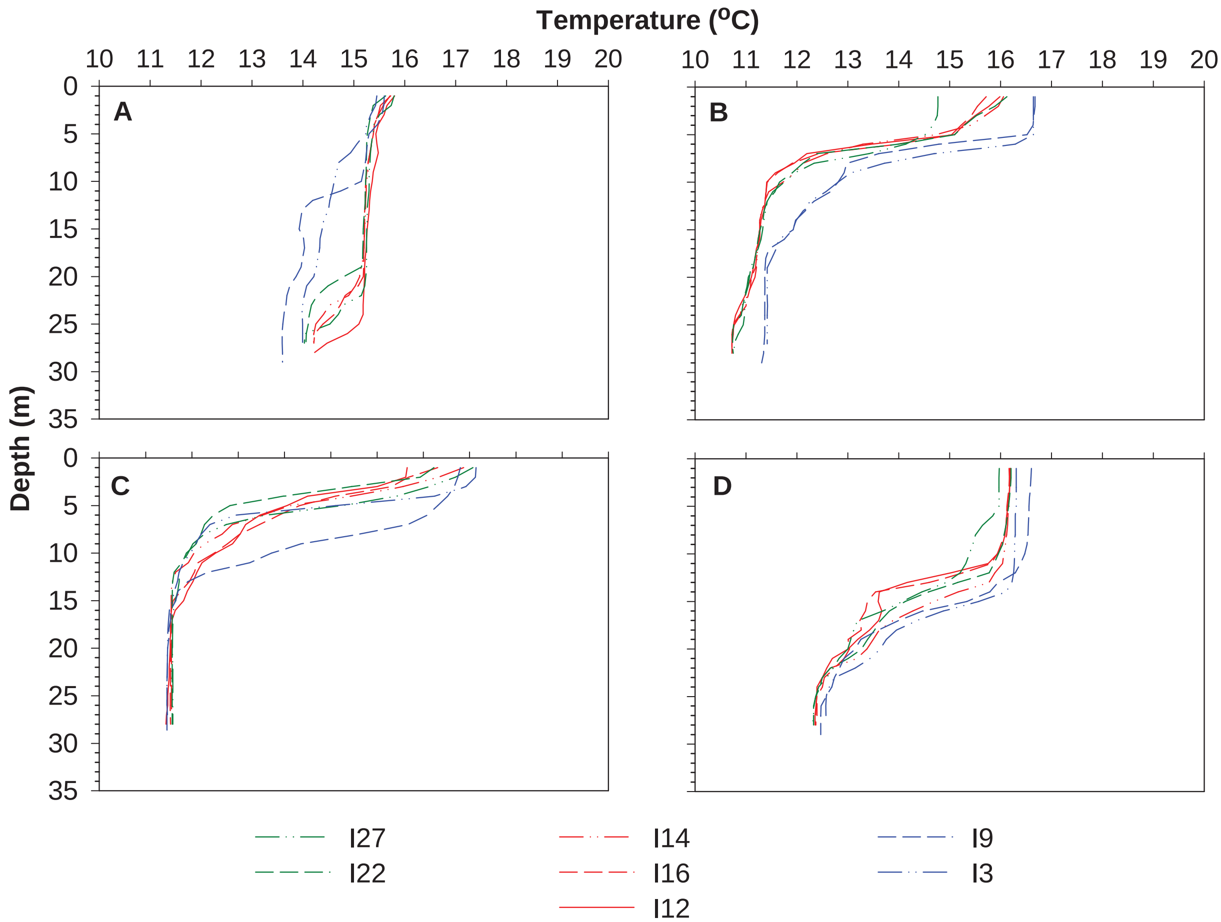

Figure 2.4
Vertical profiles of ocean temperature for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.

above (e.g., Figure 2.6). Taken together, these factors are indicative of coastal upwelling that is typical for this time of year (Jackson 1986).

There was some evidence of another region-wide phenomenon in the SBOO region during the spring, summer, and fall of 2010, when a thin layer of salinity values below about 33.40 psu occurred at sub-surface depths between ~10 and 20 m (e.g., Figure 2.6, Figure 2.7, Appendix A.2). It seems unlikely that this sub-surface salinity minimum (SSM) could be due to SBOO discharge for several reasons. First, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, results from remote sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have demonstrated that the SBOO plume disperses in one specific direction at any given time (e.g., south, southeast, north). Second, seawater samples collected at the same depths and times did not contain elevated levels of indicator bacteria (see Chapter 3). Third, similar SSMs have been reported previously off San Diego and elsewhere in southern California, including: (a) the Point Loma monitoring region during the summer and fall of 2009 (City of San Diego 2010); (b) coastal waters off Orange County, California for many years (e.g., OCSD 1999); (c) coastal waters extending as far north as Ventura, California (OCSD 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

When compared to the region-wide phenomenon described above, salinity levels were found to be even lower (i.e., <33.30 psu) at a few stations close to the SBOO at various depths during almost every survey. For example, salinity values were as low as 33.29 stations I12 and I9 during February (Figure 2.7A), when other stations never had

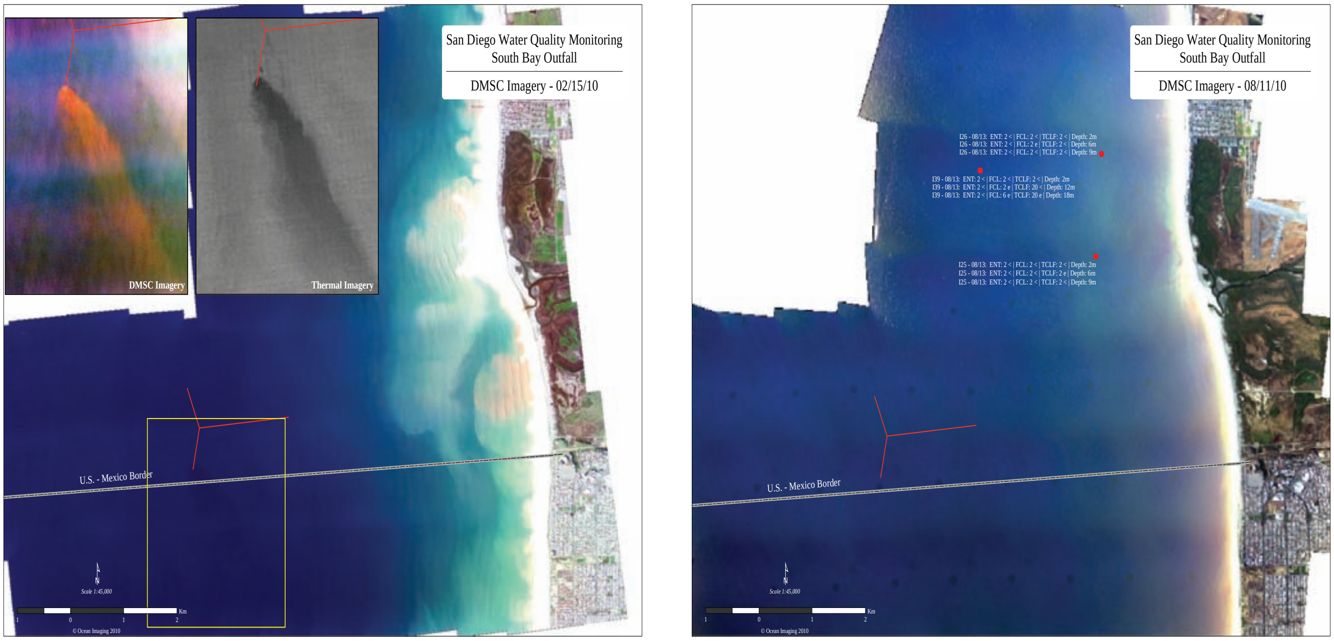

Figure 2.5
DMSC images of the SBOO and coastal region acquired on February 15, 2010, demonstrating when the SBOO plume reaches the surface (left), and on August 11, 2010, demonstrating when the SBOO plume is submerged under the thermocline (right) (see text; images from Ocean Imaging 2011).

salinity values below 33.35 psu (Figure 2.6A). Further, salinity values reached as low as 33.27 psu at stations I12, I14, and I16 during November (Figure 2.7D), which was about 0.12 psu less than other stations along the 28-m depth contour at that time (Figure 2.6D).

Dissolved oxygen and pH

Dissolved oxygen (DO) concentrations averaged from 7.35 to 10.58 mg/L in surface waters and from 2.45 to 8.37 mg/L in bottom waters across the South Bay outfall region in 2010, while mean pH values ranged from 8.02 to 8.29 in surface waters and from 7.67 to 8.20 in bottom waters (Table 2.1). Changes in pH were closely linked to changes in DO since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975).

Stratification of the water column followed normal seasonal patterns for DO with the greatest variations and maximum stratification occurring during the spring and summer (e.g., Appendices A.3, A.4). Low concentrations of DO at mid- and deeper depths during spring and summer months likely result from cold, saline and oxygen poor ocean water moving inshore during periods of coastal upwelling as indicated above for temperature and salinity. In contrast, very high DO values just below surface waters (i.e., at the thermocline) were likely the result of phytoplankton blooms as these high DO values correspond with high chlorophyll values at the same depths during the same surveys. Deviations of DO concentrations at stations close to the outfall (i.e., stations I12 and I16) were apparent only during November (Appendix A.4D). These variations were slight (<1.2 mg/L) and highly localized. The variations were so small, in fact, that they were not apparent in the 3-D graphics (Appendix A.3D).

Transmissivity

Transmissivity appeared to be within historical ranges in the SBOO region during 2010 with average values of 56–90% on the surface and 46–91% in bottom waters (Table 2.1). Water clarity was consistently greater at the offshore monitoring sites than in nearshore waters by as much as 27% at the surface and 39% at the bottom. Reductions in water clarity that occurred at various depths across the region (including stations nearest the outfall) throughout the year tended to co-occur with

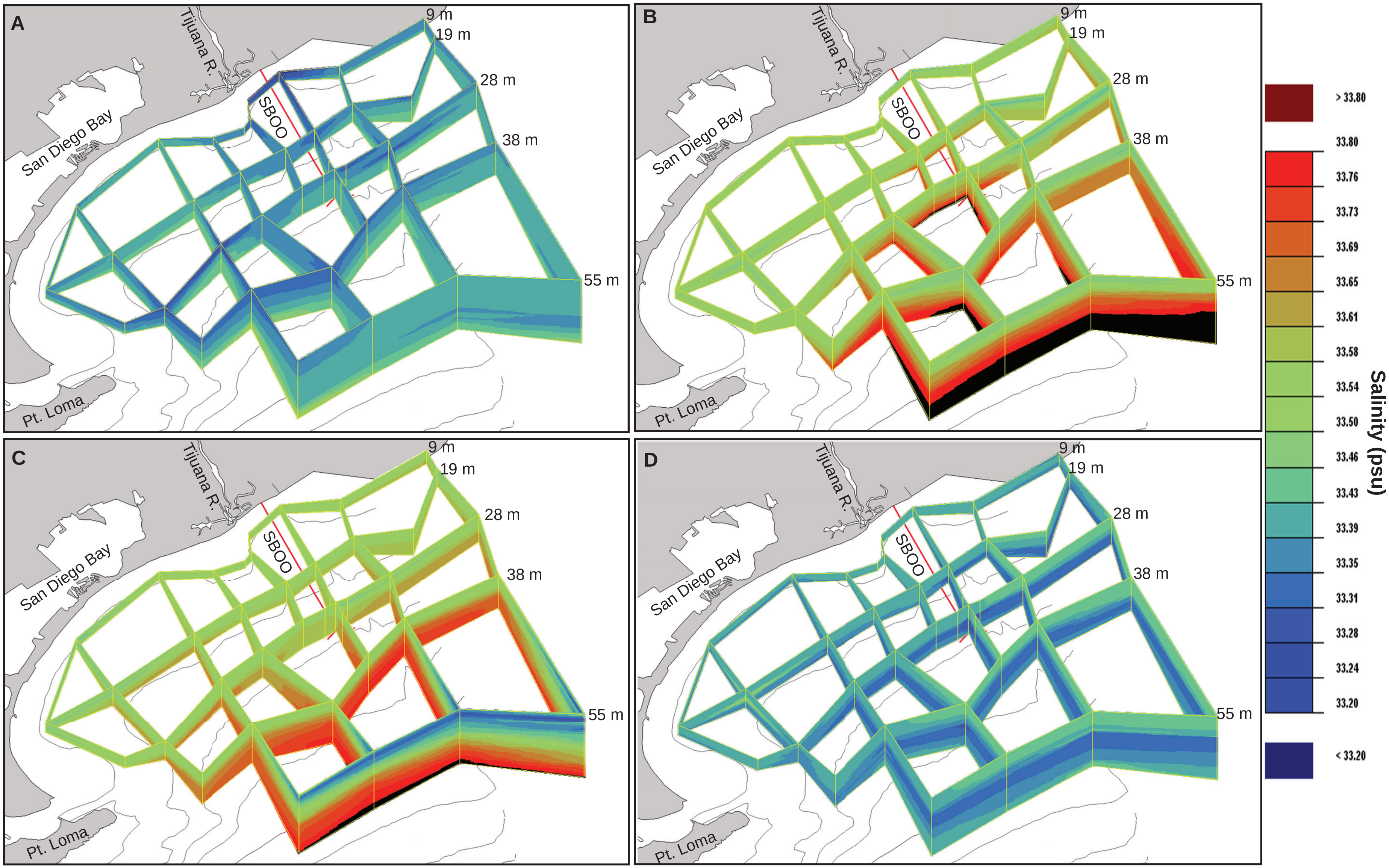

Figure 2.6

Levels of salinity recorded in 2010 for the SBOO region during (A) February, (B) May, (C) August, and (D) November. Data are collected over three days during each of these monthly surveys; see Appendix A.1 for specific sample dates and stations sampled each day.

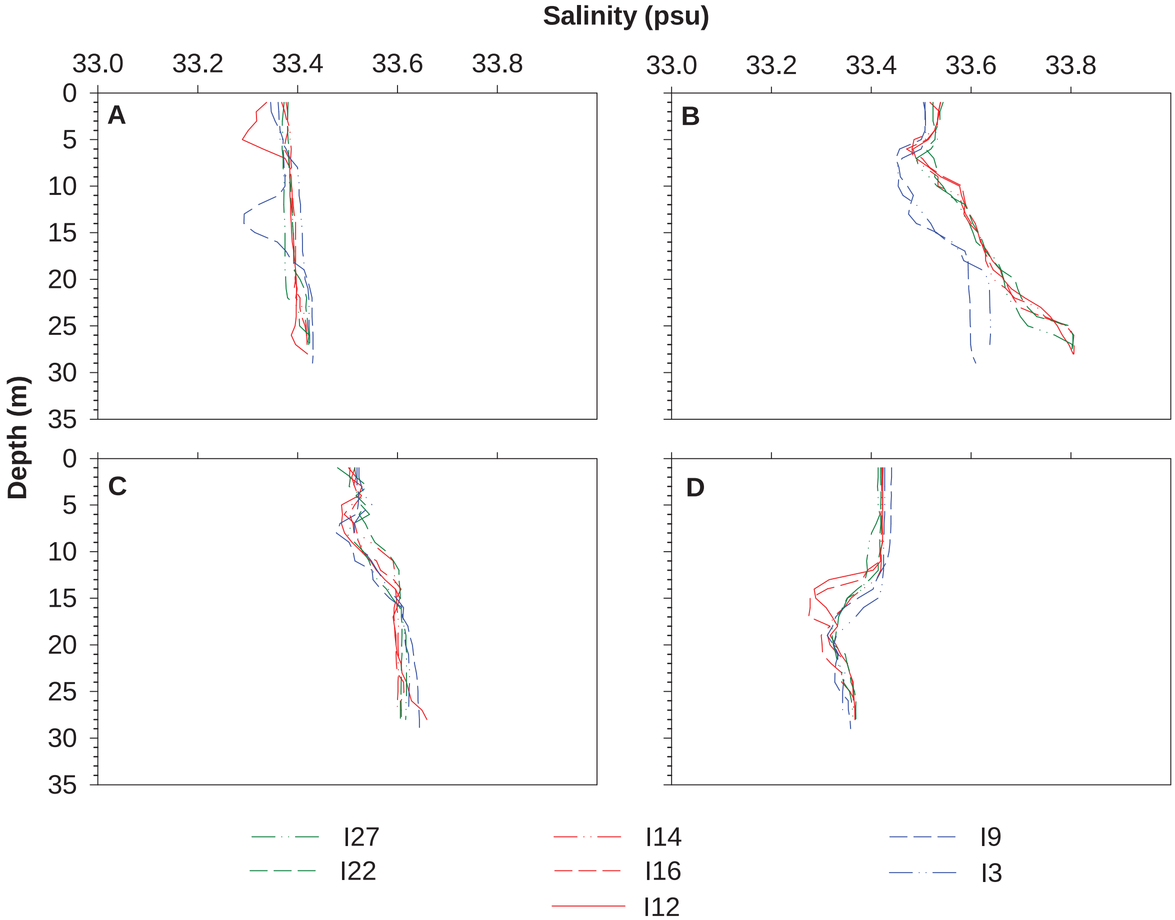

Figure 2.7
Vertical profiles of salinity for SBOO stations during (A) February, (B) May, (C) August, and (D) November 2010.

peaks in chlorophyll concentrations associated with phytoplankton blooms (e.g., Appendices A.5, A.6; see also Svejkovsky 2011). Lower transmissivity along the 9-m depth contour during the winter and fall months may also have been due to wave and storm activity stirring up bottom sediments or particulate-laden runoff. Changes in transmissivity levels relative to wastewater discharge were not discernible during the year.

Chlorophyll a

Mean concentrations of chlorophyll *a* ranged from 0.69 µg/L in bottom waters at the offshore sites during March to 40.63 µg/L at inshore bottom depths in August (Table 2.1). However further analysis clearly showed that the highest chlorophyll values tended to occur at mid- and deeper depths (e.g., Appendix A.6, A.7), reflecting the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest. The highest concentrations of chlorophyll for 2010 occurred during May and August across much of the region and corresponded to the coastal upwelling indicated by the low water temperatures, high salinity, and low DO values at bottom depths described above. The relationship between coastal upwelling and subsequent plankton blooms has been well documented by remote sensing imagery over the years (Figure 2.8; Svejkovsky 2011).

Historical Assessment of Oceanographic Conditions

A review of oceanographic data from all stations along the 28-m depth contour sampled between 1995 and 2010 did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO (Figure 2.9). Instead, these data tend to track changes in large

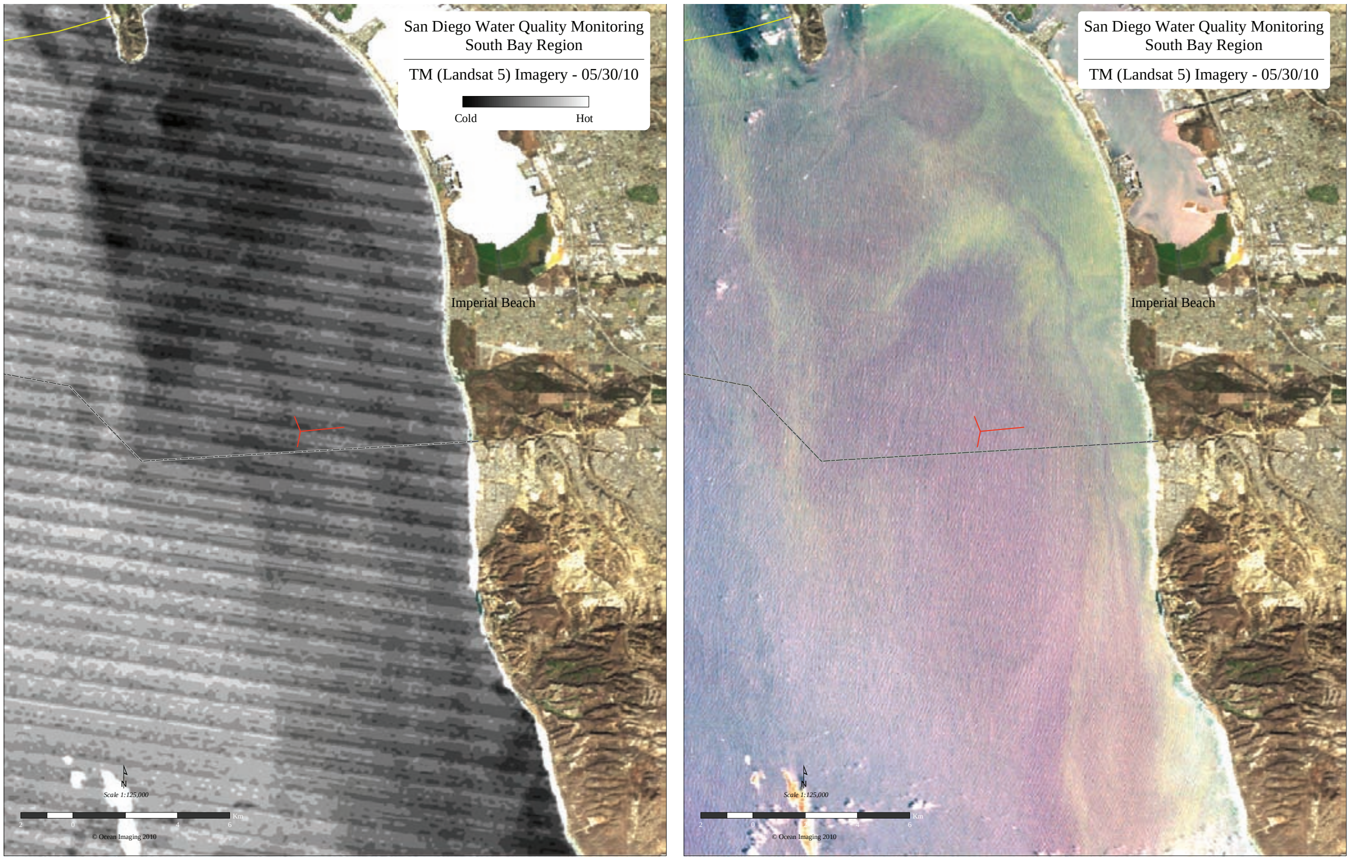

Figure 2.8
Landsat TM5 images of the SBOO and coastal region acquired on May 30, 2010, depicting a coastal upwelling event (left) and a corresponding phytoplankton bloom (right) (from Ocean Imaging 2011).

scale patterns in the California Current System (CCS) observed by CalCOFI (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, NOAA/NWS 2011). For example, six major events have affected the CCS during the last decade: (1) the 1997–1998 El Niño event; (2) a shift to cold ocean conditions between 1999–2002; (3) a subtle but persistent return to warm ocean conditions beginning in October 2002 that lasted through 2006; (4) intrusion of subarctic surface waters resulting in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña event in 2007 that coincided with a cooling of the Pacific Decadal Oscillation (PDO); and (6) development of a second La Niña event starting in May 2010. Temperature and salinity data for the South Bay region are consistent with all but the third of these CCS events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were well below the decadal mean (Peterson et al. 2006). During 2008 and 2009, temperatures remained cool, but closer to the overall average, whereas 2010 saw the return of cold La Niña conditions.

Water clarity (transmissivity) has generally increased in the South Bay region since 1999, although there have been several intermittent periods when clarity was below normal (Figure 2.9). Transmissivity was much lower than normal during the winter months of several years (e.g., 1998, 2000), likely due to increased suspension of sediments caused by strong storm activity. In addition, below average water clarity events that occur in the spring and early summer months are probably related to plankton blooms such as those observed throughout the region in 2005, 2008,

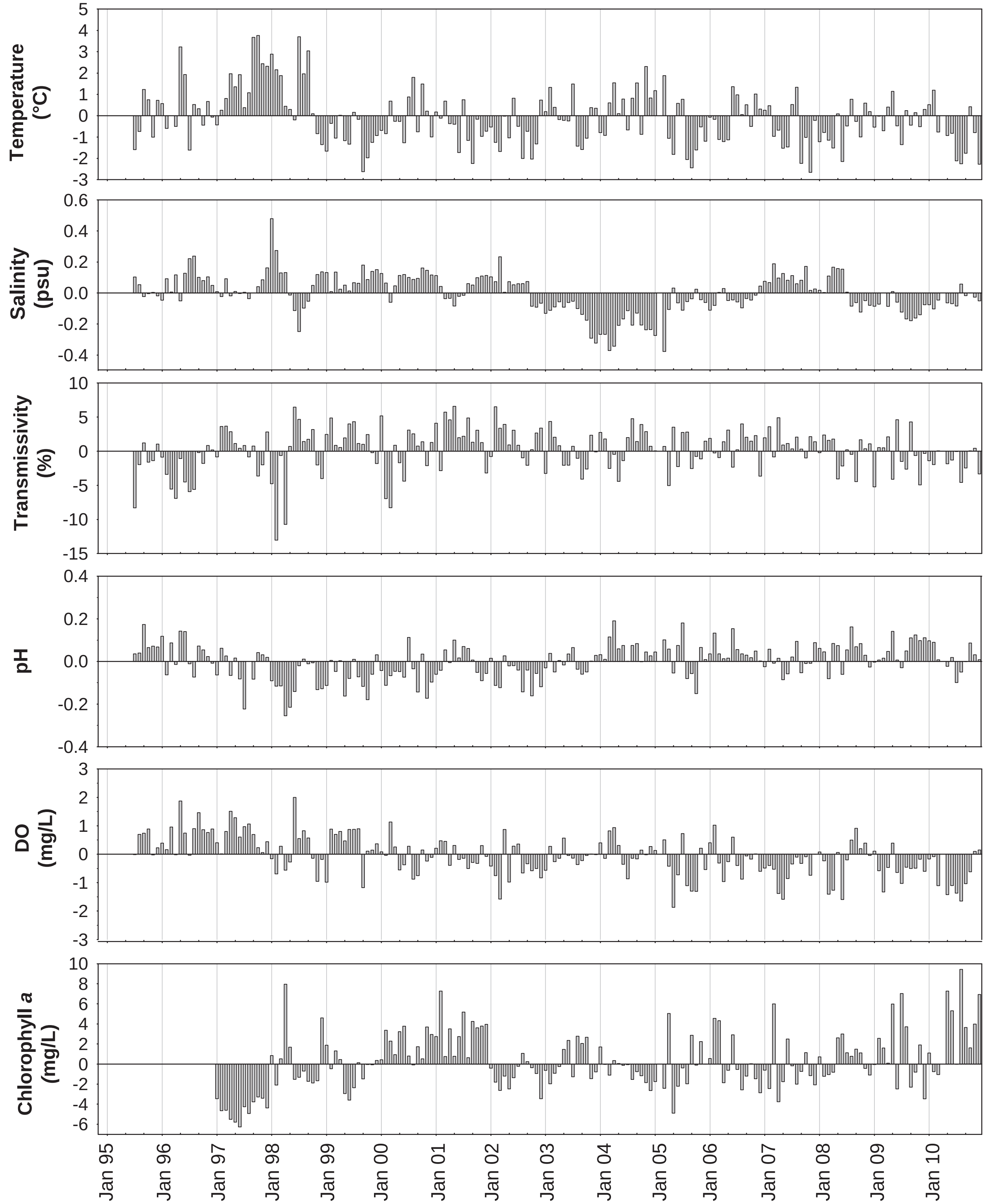

Figure 2.9

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll *a* anomalies between 1995 and 2010. Anomalies were calculated by subtracting the monthly means for each year (1995–2010) from the mean of all years combined; data were limited to all stations located along the 28-m depth contour, all depths combined.

2009 and 2010 (see City of San Diego 2006, 2009, 2010 and the discussion in the previous section). In contrast, water clarity during 2006 and 2007 was mostly above the historical average. These latter results are indicative of reduced turbidity due to decreased storm activity and lower rainfall totals of less than 11 inches for these two years.

There were no apparent trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.9). These parameters are complex, dependent on water temperature and depth, and sensitive to physico-chemical and biological processes (Skirrow 1975). Moreover, DO and pH are subject to diurnal and seasonal variations that make temporal changes difficult to evaluate. However, DO values below the historical average appear to be related to low levels of chlorophyll or strong upwelling periods.

Discussion

The South Bay outfall region was characterized by typical seasonal patterns in 2010, which included coastal upwelling and corresponding phytoplankton blooms that were strongest during the spring and summer and occurred across the entire region. Upwelling was indicated by relatively cold, dense, saline waters with low DO levels at mid-depths and below. Plankton blooms were indicated by high chlorophyll concentrations and confirmed by remote sensing observations (i.e., aerial and satellite imagery). Additionally, water column stratification followed typical patterns for the San Diego region, with maximum stratification occurring in late summer and reduced stratification during the winter. Further, oceanographic conditions remained notably consistent with changes in large scale patterns observed by CalCOFI (Peterson et al. 2006, Goericke et al. 2007, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, NOAA/NWS 2011), or they were consistent with data from northern Baja California (Peterson et al. 2006). These observations suggest that other factors such as upwelling of deep offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

As expected, satellite and aerial imagery detected the signature of the SBOO wastewater plume in near-surface waters above the discharge site on several occasions between January–March and in December when the water column was less stratified (Svejkovsky 2011). In contrast, the plume appeared to remain deeply submerged between April–November when the thermocline was stronger. Results from bacteriological surveys further support the conclusion that the plume only reached surface or near-surface waters during the winter when the water column was mixed (see Chapter 3). In addition, historical analysis of remote sensing observations made between 2003 and 2009 provides no evidence that the wastewater plume from the SBOO has reached the shoreline (Svejkovsky 2010). These findings were supported in 2010 by the application of IGODS analytical techniques to the oceanographic data collected by the City's ocean monitoring program. For example, while small salinity differences were observed at stations close to the outfall discharge site, it was clear from these analyses that any variations among stations at any particular depth were very slight and highly localized.

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